Shakeout in industrial dynamics: new developments, new puzzles

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The growing body of analysis in the field of industrial dynamics since the 1980s may lead people to think that industrial dynamics is a new domain of research. This is of course a misperception since some early contributions provided first steps towards the elaboration of an industrial dynamics approach. Schumpeter (1912, 1942) did significant work emphasising the role of the entrepreneur in the development of innovation, as well as the evolution of industry in a context of radical change. Marshall (1890, 1920) also proposed many lines of inquiry, such as the fact that the economy is composed of different sectors, the growth and decline of which is unequal and intrinsically dependent on the organisation of knowledge.

This misperception is certainly due to the fact that the post-Second World War decades were characterised by the development of industrial organization that focused on optimality properties and comparative efficiency studies of different equilibrium situations, and ignored the conditions under which an industry could emerge and evolve over time. From the late 1950s to the 1960s, the structure-conduct-performance paradigm, at the core of the Harvard tradition, focused essentially on the determinants of features of market structure and performance, such as concentration, firms' size and profitability. In the 1970s and 1980s, more attention was given to how the behaviour of firms could have an impact on market structures and performances, with the emergence of new approaches such as the Chicago School, the Theory of Contestable Markets and the New Industrial Organization. These approaches were major advances in the development of conventional industrial organization. But in retrospect they made meager contributions to the specific problem of industrial dynamics. They were not based on a dynamic framework but on a static one, and their unit of analysis is not the industry but the rational behaviour of firms.

Over the 1980s, however, there were some authors who tried to build on the neglected work of Schumpeter and Marshall, and who focused on major changes that have taken place in industry structure, industrial leadership, economic growth and innovation. The research program initiated by Nelson and Winter (1982), which focused on evolutionary theory and economic change, opened the door to new interpretations. In one of these new interpretations, Gort and Klepper (1982) tried to understand the long-term evolution of innovative industries, and assessed that this long-term evolution is essentially characterized by a life cycle in which industries, like bio-organisms, arise in their birth time, grow and mature in their development time, and decline in their death time. The industry life cycle clearly added value to the explanation of a large number of regularities occurring in innovative industries. But the

shakeout, which corresponds to a massive exit of producers, progressively became a central regularity to be explored in industrial dynamics. Most of the recent debates attempted to clarify when and why a shakeout occurs.

We can first think that technology essentially drives the life cycle of an industry, and is responsible for the shakeout. This calls to mind Schumpeter's vision of creative destruction in industrial dynamics. An entrepreneur sets up a firm to introduce his invention. This firm grows and holds a monopoly position for some time. But in time this firm is imitated by new entrants which compete severely, and eventually outperform the initial firm. This situation can last until another entrepreneur develops a new project involving the exit of older and larger firms and the entry of new ones.

But we can also think about the shakeout in a different manner. We can consider that knowledge and competencies drive the life cycle of the industry. In that case, closer to Marshall's vision, the growth of knowledge is linked to the ability of firms to ensure a coherence between internal economies (organization and direction of the resources of the firm) and external economies (general development of the economy, including the role of firms in the neighborhood). In this perspective, the shakeout affects firms differently, since some firms might have the opportunity to accumulate specific knowledge and competencies, and survive. In some cases non-shakeout patterns may thus emerge.

The purpose of this paper is to stress these different visions of shakeout in industrial dynamics, to characterize the new developments that support these alternative visions, and to clarify the puzzles that these visions may present for industry life cycle analyses. The first section provides a synthesis of the basic framework on industry life cycle proposed by Gort and Klepper in the 1980s. The remainder of the paper investigates more recent developments on shakeout, which is considered a central question in the 1990s and 2000s. The second section focuses on a conception of shakeout which is closely linked to technological conditions. The obsolescence of an old technology and the dominance of a new one involves that a new industry replaces the old one. Firms in the old industry have to face a shakeout, and these firms are generally not the main actors of the new industry. The third section focuses on an alternative conception of shakeout which is closely connected to knowledge accumulation and diffusion. A new industry never starts from scratch, as industries generally arise through a transformation of existing industries. When a shakeout occurs, firms that organized the

conditions of knowledge accumulation and diffusion may survive, and eventually become the leaders of the newly-born industry. The fourth section makes some concluding remarks.

1. Industry life cycles

The main ambition of Gort and Klepper (1982) is well known. The study attempts to measure and analyze the diffusion of product innovations and views the historical sequence or time path of events as a critical determinant of the ultimate structure of new product markets. In this perspective, the study addresses a series of new questions: How does innovation proceed over time and affect the structure of the industry? What explains the fact that information either favors or blocks entry throughout the process of innovation? What are the main regularities that drive the emergence, maturity and decline of innovative industries? Let us examine these different questions in turn.

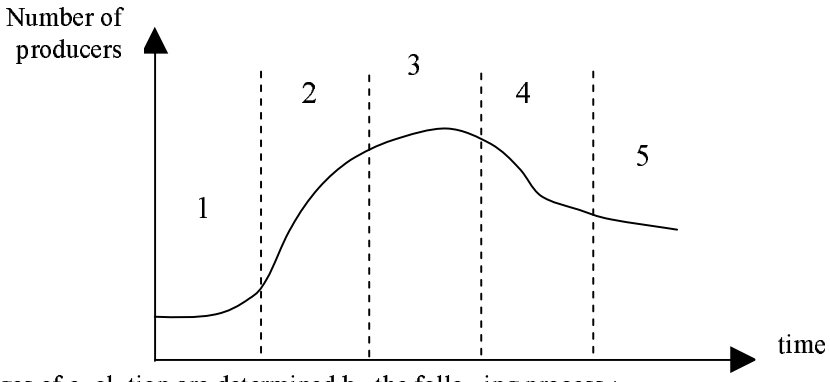
1.1. Diffusion of innovation and evolution of industry

The empirical part of the paper focuses on 46 product histories and describes how these 46 new product innovations are diffused in the market. These product histories serve as the basis for a theory of the development of industries for new products.

There are 5 different stages in product histories, which structure the development of industries and characterize the life cycle of an industry (figure 1). The first stage begins with the commercial introduction of the new product by its inventor or first producer. The size of the market is very limited, the commercial success of the product is highly uncertain, and the product is a kind of prototype to be further improved. This first period ends when new entrants start to penetrate the newly-born industry. The length of this stage depends on the ease of copying the initial innovator, the size of the market for the new product after its introduction, and the number of potential entrants into the market. The second stage is characterized by an increase in the number of producers of the new product. Growth of output is high and the design of the product is narrowly specified. The third stage corresponds to a net entry equal to zero (the number of entrants is roughly balanced by the number of exiting firms). Process innovation progressively replaces product innovation, since the process of production is more complex and has to be oriented towards a lower cost development of the

innovation. This stage ends with a decline in gross entry. In the fourth stage, there is a negative net entry, and the number of exiting firms is much superior to the number of new entrants. Finally, a large number of incumbent firms disappear, exiting the industry in the fifth stage. This phenomenon – called the shakeout – corresponds to the maturity of the industry.

Figure 1: The five stages of new product industries



The five stages of evolution are determined by the following process :

$F_t = P_t (N-n_{t-1})$

with F_t, the expected number of entrants in t ;
P_t, the probability of entry in t of each potential entrant ;
N, the population of potential entrants ;
n_{t-1}, the number of firms that have already entered the market by t-1.

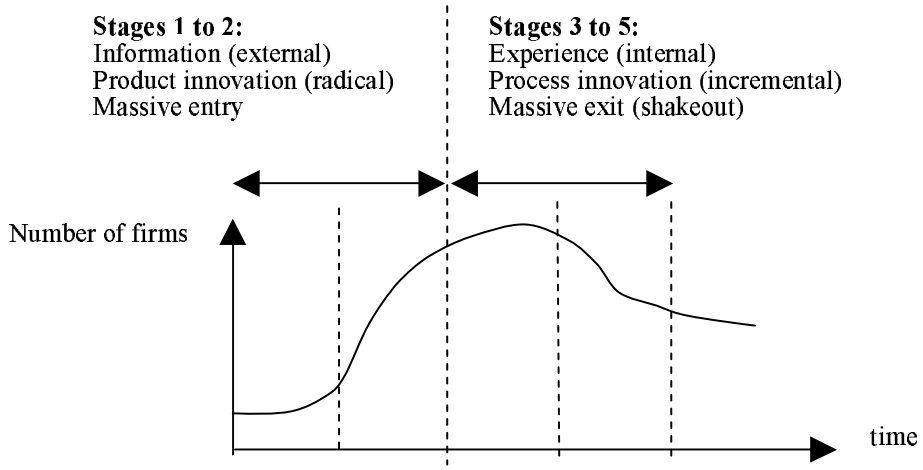
1.2. Types of information and entry/exit process

Entry is defined by a probability P_t and evolves from stage to stage according to different innovation behaviours. Innovation behaviours depend on the access to information, as well as on profit opportunities (figure 2). In stage 2 innovations essentially come from external sources of information. This first type of information is accessible to any potential new entrant and favours the process of entry, as large opportunities of profit are available. However, in stages 3 to 5, information is now more related to the experience accumulated by incumbent firms on both the nature of the new product and the process of production. This second type of information acts as a barrier to entry. Profit opportunities are more reduced for potential entrants and the process of entry stagnates progressively.

In these different stages, innovation is not considered an isolated phenomenon generating a new technological trajectory. Rather, innovation appears all along the life cycle and the nature of innovation changes as the life cycle progresses. Product innovation at the beginning of a new cycle has a major impact on production costs and product quality. Process innovation at

the end of the life cycle involves more incremental adjustments on production processes and management/marketing techniques.

Figure 2: Information, innovation and entry/exit process



Entry probability P_t is characterized by the following function :

$P_t = f(I_{2t}, L_t, \Pi_t)$

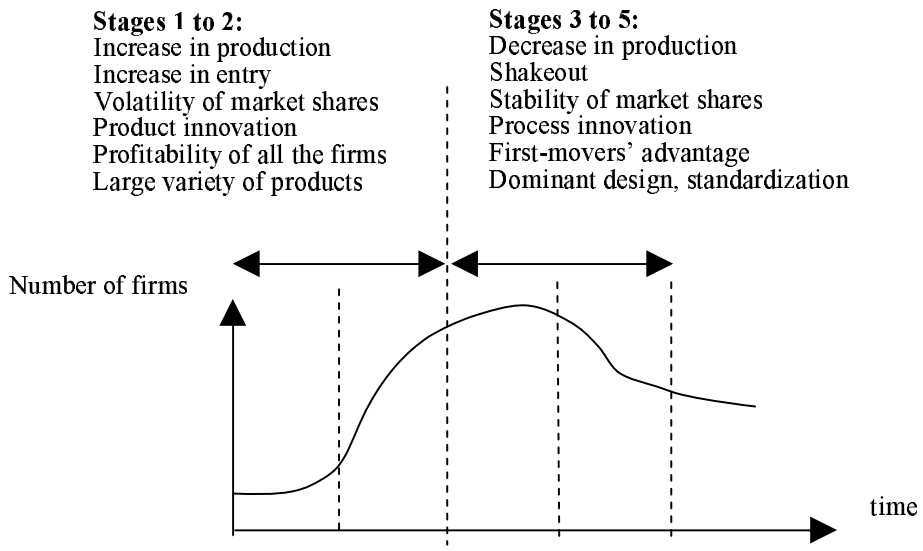
with I_{2t}, number of innovations at time t emanating from sources external to the industry ;
L_t, the accumulated stock of experience of incumbent producers ;
Π_t, profit of incumbent producers at time t ;
and $\delta f/\delta I_{2t} > 0$, $\delta f/\delta L_t < 0$ et $\delta f/\delta \Pi_t > 0$

o Regularities in emerging industries

The industry life cycle is governed by the existence of six regularities or principles of evolution (figure 3):

- production increases in the initial stages and declines in the final stages
- entry is dominant in the early phases of the life cycle and is progressively dominated by exit. A massive process of exit (a shakeout) occurs in the final stages of the life cycle
- market shares are highly volatile in the beginning, and tend to stabilise over time
- product innovation tends to be replaced by process innovation
- first movers generally have a leadership position which guarantees their long-term viability
- product variety disappears over time, as a dominant design emerges.

Figure 3: Regularities in the development of industries



2. Shakeout and the evolution of technology

The initial project of describing industry life cycles was to explore a large number of regularities in the development of industries. In the 1990s, however, the project focused more and more on the shakeout phenomenon, and attempted to clarify what occurs in pre-shakeout versus post-shakeout periods. This attention is of course related to the crucial role of shakeout in the industry life cycle: a cycle cannot be observed without a shakeout in mature stages of the industry. But shakeout is also a key to understanding why a given industry is declining, and why major actors of this industry tend to be superseded by new actors creating a new industry. Behind this, there is the idea that a given technology can create profit opportunities for some time, but that new technologies will recurrently be created and replace older ones. This Schumpeterian vision of the dynamics of an economic system has been explored in recent contributions on the shakeout in industry life cycle, with an emphasis on different determinants. A series of empirical results has also been completed to validate the predominance of a life-cycle in innovative industries.

2.1. Shakeout and dominant design

Abernathy and Clark (1978, 1985), Clark (1985), and Utterback and Suarez (1993) develop an analysis of shakeout which is derived from the traditional Schumpeterian hypothesis on the

R&D advantage of large firms. Large firms are generally engaged in important R&D programs which generate new products. When a large firm selects one of these new products and decides to launch it on market, this large firm must face a high level of uncertainty affecting both the conditions of demand and supply. On the demand side, uncertainty comes from the fact that the firm does not know the details of customers' preferences, namely preferences related to the various possible characteristics of the product innovation. On the supply side, the conditions of production are also highly uncertain and may evolve over time. Different producers can thus experiment various product innovations with distinct characteristics, and implement different processes of production. These alternative producers thus engage in a process of competition.

Over time, however, uncertainty decreases and selection operates. On the demand side, uncertainty decreases once customers of the new product have tested the alternative characteristics, and acquired experience on what they expect from the new product, which characteristics are more adapted to their personal taste and usage. Eventually customers select a series of product characteristics and demand becomes more predictable. On the supply side, rival producers learn over time and accumulate experience on what customers prefer. In time they also select a series of production techniques which are adapted to low cost production.

Since uncertainty decreases, the shakeout appears as an endogenous phenomenon. Product innovation diminishes because most of the actors (producers and customers) are naturally oriented towards the production and consumption of a standardized good. The progressive emergence of a dominant design involves higher barriers to entry which correspond with investments by incumbents in process innovation. Entry is thus limited, and less efficient incumbent firms exit the industry.

- **Shakeout and technological shock**

Jovanovic and Mc Donald (1994) propose a very different vision of shakeout. For these authors shakeout is generated by an external technological shock, exogenous to the industry. The first technological shock sets in with the development of the new product being launched on the market. Entry is stimulated by the emergence of new profit opportunities related to this new technology/new product, but subsequently there is a progressive reduction in profit margins and the industrial structure stabilizes on a limited number of firms in the industry. At

this stage, which corresponds to the maturity of the industry, a new technological trajectory emerges and again stimulates the process of entry, in the meantime, involving an adjustment of incumbent firms. The process of adjustment is driven by a stochastic process and only a few firms survive this external shock. The shakeout thus eliminates firms which failed to adapt themselves to the new technology.

- **Shakeout and timing of entry**

Finally, Klepper (1996) relates the shakeout to the timing of entry. The reference is, here again, the Schumpeterian hypothesis on the relation between firms' size and R&D capacity. But the novelty is that this hypothesis is discussed on the basis of a finer distinction between firms which can eventually be incumbent, new entrant, or latecomer.

Process innovation decreases the average costs of large firms, which are the major actors of this type of innovation. However, some key elements may erode the advantage of larger firms. For instance, large firms have to cover specific costs, such as expansion costs, which limit their growth. The activity of R&D can also exhibit decreasing returns to scale over time. Because of these elements, early entrants can develop process innovations, sometimes much better than incumbents or latecomers. Early entrants can thus enjoy a leadership position in process innovation as, on the one hand, incumbents have to deal with other problems which are related to their large size and, on the other hand, latecomers have to concentrate on product innovation which allows them to grow to a minimum size in order to survive. The timing of entry is thus a major determinant in the formation of a competitive advantage over incumbents, as well as in long term survival over latecomers. This mechanism provides an alternative explanation of the shakeout.

- **Empirical studies on shakeout**

In their pioneering work, Gort and Klepper (1982) considered 46 different industries and showed that they evolved according to a life-cycle. More recently, Agarwal (1998) completed the time series until 1991, and confirmed that the industries which were in their maturity stage in the early 1980s faced a shakeout in the decade. The initial program which was based on research of large empirical validation appears to have been maintained today (see also Klepper and Graddy, 1990).

However, most of the contributions in the late 1990s, tend to determine a limited set of industries whose evolution largely conforms to the industry life cycle. Some of the 46 initial industries therefore deserve special attention: automobile, typewriters, automobile tires, commercial aircraft for trunk carriers, televisions, television picture tubes, and penicillin (Klepper, 1997; Klepper and Simons, 1997, 1999; Klepper, 2002). And shakeout is of course one of the main regularities to be investigated empirically within these industries.

An important part of the investigation concerns the definition of shakeout. In most cases, shakeout was considered a massive exit occurring in the maturity stage, which involved negative net entry rates. Klepper and Miller (1995) clarify this definition. They stress that a product is deemed not to have experienced a shakeout if the number of firms never declines below 70% of the peak number, or if it does but subsequently recovers to over 90% of the peak.

Another part of the research concerns the determination of the most dominant explanation of shakeout in these industries (Klepper and Simons, 1999). The different theses on shakeout – shakeout and dominant design, shakeout and technological shock, shakeout and timing of entry – are thus competing with each other, and the following results emerge from this empirical confrontation. The more a firm ages in the industry, the lesser is its probability of exit. As a matter of fact, firms which penetrated the industry before the shakeout, and compose thus the cohorts of pre-shakeout, have the lowest exit rates when the shakeout occurs. Green *et al.* (1995) show that most of these firms capture large market shares and produce a large spectrum of products. On the contrary, cohorts of post-shakeout which regroup younger firms and latecomers are characterized by the highest exit rates. Some of them survive (Agarwal and Gort, 1996), but occupy small market niches (Klepper, 1997). It appears, moreover, that the first movers' advantage which benefits the cohorts of pre-shakeout is directly connected to their capacity of adjustment in terms of innovative behaviour (from product innovation to process innovation). Shakeout is thus essentially driven by timing of entry, and to a lesser degree by alternative explanations which include the emergence of a dominant design or a new technological trajectory.

3. Shakeout and evolution of knowledge

The idea of a shakeout essentially driven by the evolution of technology over the course of the industry life cycle is progressively challenged by a new vision. Henderson (1995) shows that the traditional technology of optical lithography used in the semi-conductors industry should have been replaced by new and superior technologies such as X-rays or electrons. This traditional technology nevertheless persisted and had an unexpected long old age since the final users continued to privilege this technology, and a specific organization of the industry was implemented with firms developing complementary competencies. Moreover, Mueller (1990, 1997) shows that the long term viability of first movers is related in a large number of industries to specific features of demand (such as set-up and switching costs, network externalities of final users, inertia effects due to the customer's uncertainty on quality, inertia effects due to the customer's experience of existing products and services), as well as supply (such as set-up and network externalities of producers, economies of scale, cost-decreasing learning by using). Finally, Van Dijk (1998) shows that increasing returns in R&D is not the major element in the first movers' competitiveness, but that network effects have a rather decisive effect. The development, accumulation, diffusion and usage of competencies are thus key elements which drive the industry-life cycle and, as an outcome, involve a sensibly different vision of shakeout which is closer to the Marshallian tradition.

3.1. Shakeout and complementary competencies

Industry life cycle analyses generally focus on industries in which competition and innovation proceed from the interaction between firms (incumbents and entrants) within a given market, delimited by the purchases and sales of an homogenous product. On some occasions, however, vertical relationships between firms in the industry and their direct suppliers or customers have a strong impact on the evolution of industries. Innovation processes require the accumulation of complementary competencies, as well as an effective coordination between firms which generate these competencies. Since the industry is characterized by strong coordination between suppliers and producers, or producers and retailers, processes of entry and exit become industry-specific. Alternative life cycle patterns thus appear, eventually with non-shakeout phenomena.

In some industries the emergence of specialized suppliers tends to re-dynamize the entry process in the phase of maturity. They develop new production processes, new specialized equipment, new technology at the upstream level and sell it to any downstream potential entrant who can pay the price. They significantly decrease barriers to entry and favor competition. This mechanism of accumulation and transfer of new competencies is observed and documented in various industries.

In chemicals and petrochemicals, production has increased rapidly after World War II in the US. After 20 years of successful commercialization of various products (styrene, synthetic fibres and plastics), a large number of specialized engineering firms emerges to service the producers. These specialized suppliers develop new methods of production which can be acquired by both incumbents and new entrants in petrochemicals *via* patents and licenses. Thus, although the US chemical industry has enjoyed an early advantage in petrochemicals, this advantage has been progressively eroded as technologies diffuse, enabling Europe and Japan to narrow the gap and other countries to enter the industry. Increased competition, compounded by the oil shock of the 1970s and slowing possibilities for significant product innovations, culminates in a continuing process of restructuring. The restructuring results in more product focused firms and more globalized firms. It also generates a reduction in R&D intensity in virtually all sub-sectors, except the life sciences which were traditionally a part of the chemical industry but are now a separate industry (Arora, Landau, Rosenberg, 1998).

In telecommunications, liberalization occurs in the mid 1980s in the US and continues until the late 1990s in Europe. Liberalization is intended to generate a larger spectrum of products and services, with low prices stimulated by intense competition between the incumbents (historical monopolies, generally state-owned) and the new entrants (large diversified groups or small start-ups). A key feature in this period is the fact that incumbents, which have long experience in R&D within large R&D-dedicated research laboratories, decide to delegate this activity to the equipment suppliers located upstream. These equipment suppliers thus have the opportunity to play a major role in the development of new equipments (terminals, networks) which are necessary to exploit new market opportunities (integrated systems for the transfer of voice, data, and video, with friendliness, security, reliability and mobility). These equipment suppliers therefore stimulate the entry process of newcomers in the telecommunications industry and for some permit long term viability (Fransman, 1999; Fransman and Krafft, 2002).

In other cases, the industry was created by an initial inventor or an academic researcher who decided to set up a firm to exploit the commercial opportunities of his innovation. Many times, however, the production and distribution of this innovation required the contribution of other actors, usually larger firms. The coordination of competencies related to innovation on the one hand, and complementary competencies related to production and distribution on the other hand, strongly shaped the profile of evolution of the industry, and stimulated new entries.

In medical instruments, product innovation (X-rays, RMN, computed tomographic) is implemented by small start-ups, connected to academic research. These firms are highly specialized and, as the market expands remarkably, they rely more and more on other firms for production and distribution facilities. These other firms are not de novo entrants, but rather incumbent producers of prior imaging instruments. Yet with the penetration of the new activity (diagnostic imaging instruments), they significantly extend their competencies. Ultimately, they favor the entry of a new cohort of entrants composed of firms specialized in other complementary competencies such as computed security and testing (Mitchell, 1995; Klepper, 1997).

3.2. Shakeout and similar competencies

The coordination of similar competencies is also an important topic for researchers interested in how innovations occur and their implications for firms and economic change. In some industries there is a somewhat paradoxical phenomenon that both small, specialized firms and large, diversified firms co-exist in the long run. Specific firms may come and go, and there are certainly mergers, alliances, and bankruptcies, but the two types of firms seem to an extent mutually dependent on each. This situation may lead to non-shakeout profiles of evolution, with small firms and large firms surviving over the long run.

In biotechnology, networks, clusters and alliances are crucial to the co-existence of similar competencies developed by large and small firms, even though large firms progressively retain control over the networks. It seems important to combine such alliances with in-house R&D and competencies, because otherwise the firm has difficulties in evaluating the potential of new ideas and techniques that are developed outside the firm. In many cases, the intrinsic

characteristics of knowledge in terms of codification and appropriability requires extended interaction, and explains why collaboration occurs amongst firms with similar competencies in order to stimulate innovation. But in the meantime, ownership and control rights are important to understand who has alliances with whom and are absolutely crucial in the evolution of the industry (Mc Kelvey, 1996; Saviotti, 1998).

3.3. Shakeout and final users

When demand is highly diversified, a large spectrum of firms can survive in specific market niches. Their long term viability is essentially based on their capacity to develop competencies in terms of the products and services customers expect. This greatly favors mechanisms of co-production, co-design and co-innovation, in which customers are highly involved in major stages of development of innovation. As a by-product, non-shakeout patterns can emerge within these industries (Nelson, 1998; Windrum and Birchenhall, 1998).

In the aircraft industry, for instance, buyers of business jets are generally characterized by the value they place on aspects such as size, speed, distance and manoeuverability. A large series of aircraft have thus been developed to service these varied needs and firms generally offer only selected aircraft types corresponding to a limited range of buyers. Producers within this submarket are thus highly specialized and clearly engaged in a made-to-measure supply process. This pattern of evolution stands in sharp contrast with the traditional commercial aircraft industry, in which only two firms survived (Boeing and Airbus) after an important and rather traditional shakeout (Klepper, 1997). Related aspects on networks and vertical relationships as major non-shakeout determinants emerged in the engine market segment (Bonaccorsi and Giuri, 2001)

In electronics, the emergence of a dominant design, together with a stable oligopoly of producers, is not necessarily achieved. In a sense, the technological convergence which is observed in this industry does not involve product convergence. On the contrary, an increasing process of diversification and market segmentation appears to occur on the basis of a more intricate relationship between the producers and users of the new technology (Gambardella and Torrisi, 1998; Ernst, 2001).

4. Concluding remarks

The notion of shakeout in industrial dynamics has thus stimulated new developments which, in the meantime, involve new puzzles. As a matter of fact, many industries evolve according to the industry life cycle principles. These then face a shakeout when the technology at the origins of the industry is progressively outperformed by a new technology introduced by new entrants. But at the same time many industries do not conform to the industry life cycle framework, either because they are essentially knowledge-driven instead of technology-driven, or because they exhibit non-shakeout patterns of evolution. From what emerges in the previous sections, we should say that the latter two reasons are not mutually exclusive, but rather connected to some extent. Because of the crucial role of networks, clusters, alliances and cooperations in knowledge-intensive industries, a shakeout does not necessarily occur, or if it does, occurs differently than in technology-driven industries. Namely, if the shakeout occurs within these industries, it will affect firms not taking part in a network in which competencies are actively created and coordinated.

Another key puzzle lies in how we define the industry, and which level of aggregation is adequate to characterize a shakeout. The usual procedure is to define the industry on the basis of a specific market in which similar, non-differentiated products are offered by producers and acquired by customers. In knowledge-intensive industries, however, this common procedure only provides a partial outlook on industrial dynamics since suppliers, clients and eventually partners play a crucial role in the evolution profile of the industry. The analysis must thus integrate the role of these actors to determine whether shakeout or non-shakeout patterns are observed in industrial dynamics.

Finally, the current focus on shakeout may eclipse other key problems of industrial dynamics. Industrial dynamics basically analyses the way in which the activities undertaken within the economic system are divided up among firms: some firms embrace many different activities, while for others the range is narrowly circumscribed; some firms are large and others small; some firms are vertically integrated but others are not. Industrial dynamics should therefore describe and clarify how the industry is organized now, how it differs from what it was in earlier periods, as well as what forces were operative in bringing about this reorganization of the industry and how these forces have been changing over time. The study of industrial

dynamics demands a permanent and sound connection between facts and theory. The stimulus provided by the patterns, puzzles and anomalies revealed by systematic data gathering and careful collection of detailed information – not only on shakeout but also on other conjectures – is essential to better understanding of the forces that determine the dynamics of industry.

In that respect, the research agenda in industrial dynamics should not be too restricted and should at least continue to proceed along the path opened up by Marshall and Schumpeter (Krafft, 2000, 2002). It should further elaborate taxonomies of industrial evolution in order to define some groups of industries that evolve in a similar way (Pavitt, 1984; Malerba and Orsenigo, 1993; Geroski, 1995). The identification of the main relationships between firms, suppliers, customers, competitors and, more generally, governmental, scientific or financial institutions must improve (Malerba and Orsenigo, 1996). The link between the evolution of industries, innovation and economic growth, and their implications at the local, national and international level also deserves a specific attention (Lazonick, 1991; Malerba, Nelson, Orsenigo, Winter, 1999; Lamoreaux, Raff, Temin, 1998).

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